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CONFERENCE PAPER

Some properties of pellets made of spruce and beech torrefied sawdust

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ABSTRACT

The paper aims to determine the physical properties (density) and calorific ones (calorific value and ash content) of pellets made of spruce and beech sawdust, thermally treated at temperatures of 170, 190 and 210 °C, for 1, 2 and 3 hours. After the thermal treatment of the sawdust, its mass loss was obtained, and compressed pellets were obtained under laboratory conditions. The results obtained from sawdust treatment indicated a weak increase in calorific value, depending on the temperature and the thermal treatment times. The final conclusion of the paper is that the thermal treatment improves the caloric properties of sawdust pellets, the beech sawdust having a higher capacity for torrefaction and compaction related to spruce sawdust.

Keywords: Ash content, calorific value, thermal treatment, wooden pellets

1. INTRODUCTION

Wooden pellets are obtained from sawdust with a certain granulometry, compressed to a density usually over 1.0 g cm^{-3} [1]. The sawdust is not cut especially for this use and is taken from other factories as timber, such as wood waste. From this point of view sawdust can be considered as a sort of wooden biomass. At worldwide level, biomass covered about 70% of the energy necessary in the year of 1870. Then, biomass lost high level in front of methane gas, coal and photovoltaic fuels. Currently, biomass continues to be the main fuel from which the energy in the countries with ongoing development is produced [2]. During the last years, there have been noticed favorable changes in the energy field, by obtaining energy from alternative non-conventional sources. The European Union wishes that the production from alternate sources reaches 20% in the year of 2020, of all the produced energy [3, 4]. Reaching this threshold implies a series of other factors favorable to development, and there are mentioned the emissions of carbon dioxide, which, in comparison with the year of 1990, until 2020 must decrease with 20% [5] according to the proposals of the European Union, by using and exploiting alternate sources of energy [6]. Using of energy crops such as Salix viminalis [7] conducted to use of whole biomass from harvesting and transforming it into pellets and briquettes with superior characteristics.

Biomass is environmental friendly because the dioxide of carbon is absorbed by plants during growth and will forms a closed circuit [8], because the carbon dioxide quantity which was absorbed by plants during growth will be equal with the same quantity eliminated during the complete combustion process (Fig 1). From this point of view the use of wooden biomass in combustion has a neutral effect and all combustibles from biomass are environmental neutrally.

The wooden pellets are state-of-the-art lignocellulosic energy products, obtained from small size lignocellulosic biomass (dust, sawdust and fine chips) and compacted under the form of cylinders with usual diameter of 6-10 mm [9, 10]. The pellets are engineering fuel products, which incorporate a high technology. Their dimensional uniformity, the density

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and other mechanical features make possible the automated process of the combustion and autonomy of the thermal plant of 12-24 hours [11].

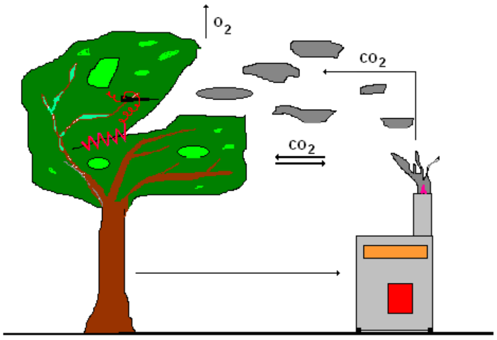


Fig 1. Closed circle of CO_2 of biomass combustion inside the naturally environment

The advantages of pellets using are as follows: they offer a reduction of fossil fuels dependency; they are renewable fuels, obtained from the small size lignocellulosic biomass; they are not degradable during storage, due to the low level of moisture content and the fact that they are delivered and kept as wrapped at about 10 % moisture content; they have a good energetic value, equivalent of the raw material from which is made; they have a very high energetic density, much higher than the one of massive wood and briquettes. The disadvantages of pellets are weakly, especially when they are compared with the lignocellulosic briquettes [12, 13]. But, when they are compared to fossil fuels or fire wood, there are a couple of disadvantages, among which the following are evidential [14]: difficult processing of raw material in order to obtain the finite product, in comparison with the fossil fuels where only their extraction is needed; additional investment towards the use of fire wood [15]; collection and processing of the ash resulted after combustion [16].

Even if the pellet machines are different [17], the features of the pellets are almost identical. Pellet properties are constantly because they are subject to a multi-state international standard. The limitative technical features of the pellets expressed by the European Standard EN 14961-1 [18, 19] are: diameter of 4-10 mm; length smaller than 50 mm; bulk density of 650 kg m^{-3}; effective density higher than 1200 kg m^{-3}; moisture content lower than 8%; ash content lower than 1.5%; calorific value of 16.9-19.5 MJ kg^{-1}. These characteristics are almost the same all over the world.

Torrefaction of wooden material is a dry thermal process, which started from the premise of reducing the higroscopicity and biodegradability. The beginning of the torrefaction process was applied firstly to tobacco, then to the timber, followed by the plywood, the chipboard, the pile and of course to the briquettes and pellets. The issue of increasing calorific power of treated pellets was less researched [20], [21]. Also, the increase in ash content during torrefaction was less researched, the increase being due to carbon enrichment by torrefaction treatment [22, 23]. One last problem less researched is the use of torrefied sawdust to create stable and less flamboyant pellets. Being a relatively new process, this thermal treatment has many unknowns and each research in this field will try to find those areas still untested or not enough researched.

Main objective of the paper is to research the sawdust torrefaction treatment with weak temperature of 170-210 °C inside of low-oxygenated oven, with direct influence upon of some pellet characteristics. This influence will be directional toward the density, calorific value and ash content of spruce and beech sawdust and pellets.

2. MATERIALS AND METHOD

There were used two types of sawdust species, respectively spruce (Picea abies L) and beech (Fagus sylvatica L), both of them taken from a circular saw of practice laboratory when these species were cut. In order to obtain a good thermal treatment and to create a dimensional uniformity of the sawdust particles there were used two sieves with the dimensions of 3x3 and 1x1 mm, eliminating the extreme particles from the sorting operation with these sieves. Then the sawdust of both species was conditioned for 48 hours in order to obtain a moisture content of about 10%. From this sawdust there were produced the blank pellets, which will be still used for comparison with the ones made of torrefied sawdust.

For the thermal treatment of sawdust a Memmert (German producer) oven was used which has had the possibility to raise the temperature toward 220 °C. The sawdust was placed on metallic crucibles, previously cleaned and weighed. First, the sawdust was dried to a constant mass at a temperature of 105 °C, after which it was weighed and noted down all the crucibles mass. Thereafter, the crucibles were introduced into a controlled cooking oven at a temperature of 650 °C, at which the air inlet was closed, and the torrefaction occurred in a poorly oxygenated environment. After 1 hour, the first batch of crucibles was removed and weighed to a precision of 0.001 g. They were placed in the conditioning chamber in order to bring them to a moisture content of 10%. After the torrefied sawdust was conditioned, there were made pellets with a diameter of about 12 mm and a mass of 0.5-0.9 g. After two hours of treatment, the second batch of crucibles was extracted from the oven and after 3 hours the last batch of crucibles was extracted. From each batch some pellets are made, but it also preserved some materials that will be used to determine the ash content. Then, other quantity of sawdust was torrefied at 190 °C and 210 °C, following the same procedure as it was used at 170 °C. In this way there were obtained pellets from torrefied sawdust at temperatures of 170, 190, and 210 °C, and at 1, 2, and 3 hours of treatment [24].

The pelletisation was performed with a hand-operated press device, an existing device that equipped the calorimeter used to determine the calorific power. The obtained pellets were introduced into sealed polyethylene folium, specifying the type of wood species (spruce, beech, control/ torrefied) and the torrefaction degrees (170/1; 170/2; 170/3 and so on, where 170 is temperature in °C and 1, 2, and 3 are time of torrefaction expressed in hours).

For determination of the effective density of the pellets, there were chosen randomly 10 pieces of pellets, each ends have been polished by grinding in order to get a surface perfectly perpendicular on their length and lastly a right circular cylinder. Therefore, keeping into account the volume of circular cylinder, the below relation has been used:

$$\rho_{ef} = \frac{4m}{\pi d^2 l} 10^3 \ \text{[g cm}^{-3}\text{]} \qquad (1)$$

Where: m is pellet mass, in g; d- pellet diameter, in mm; l-pellet length, in mm.

The installation used for determining the caloric power of the pellets was the explosive burning calorimeter type XRY-1C, produced by Shanghai Changji Geological Instrument Co. from China. This calorimeter used o bomb (Fig 2a) with high oxygen pressure of 30 bar and had an own soft for work and express all results (Fig 2b).

(a) (b)

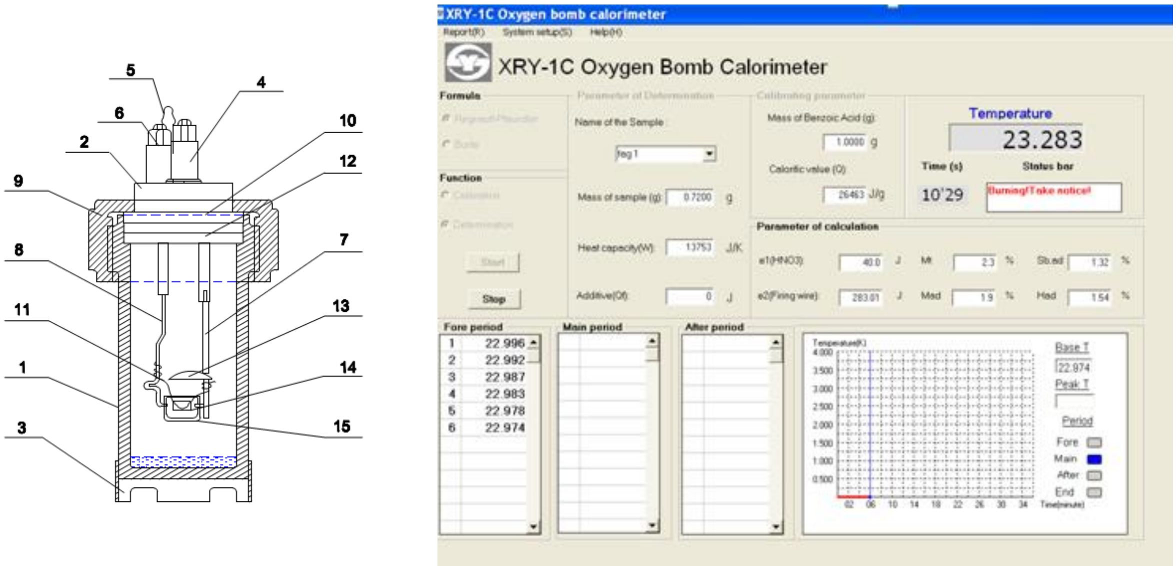


Fig 2. Determination of calorific value: (a) Section view through calorimetric bomb; 1-body, 2-lid, 3-socle, 4-couple of current 1, 5-admision of oxygen, 6-couple of current 2, 7-metal fir, 8-metal fir 2, 9- gasket 1, 10-gasket 2, 11-pellet, 12-protective sheet 1, 13-protective sheet 2, 14-nikel wire, 15-crucible; (b) interface of computer soft

Before to the test, the calibration of the calorimetric bomb was made with benzoic acid, with a known value of caloric power (26 463 kJ kg^{-1}).The method to determine the caloric power of the wooden material referred mainly to the preparation of the raw material and the installation, then to the proper determination and finally to the obtaining of the results [25, 26].

The test has contained of three different stages:

-The initial stage ("fore") had as purpose the determination of temperature variations of water in the calorimetric recipient, due to the heat exchange with the exterior before burning;

-The main period ("main") began by burning the sample and has as consequence the increase of water temperature in the calorimetric recipient, due to the burning of wooden particles and heat delivery to exterior;

-The final period ("after") had as purpose the determination of the average water temperature in the calorimetric recipient, due to the heat exchange with the exterior after burning.

The caloric power for both non-torrefied and torrefied pellets had been determined using at least 10 samples (in the form of compacted pellets) of 0.6-0.8 g. The calculation relation for the calorific power determination was:

$$CV = \frac{C(t_f t_i}{m} - q_s \ \text{[kJ kg}^{-1}\text{]} \qquad (2)$$

where: CV is the caloric power (kJ kg^{-1}); C-calorimetric constant, determined by calibrating the device with benzoic acid (kJ(°C)$^{-1}$); t_f- final temperature, read by the thermocouple of the calorimeter, °C; t_i- initial temperature, read by the thermocouple of the calorimeter, °C; qs- heat quantity issued by the nickel and cotton wires.

The increase of calorific power (ICV) (but also for other parameters determined in the paper) from one thermal regime to another was determined with the following relation:

$$I_{CV} = \frac{FV_{CV} - IV_{CV}}{IV_{CV}} \cdot 100 \ [\%] \qquad (3)$$

where: FV_{CV} is final value of calorific value; IV_{CV}- initial value of calorific value.

Determination of the ash content used non-torrefied sorted sawdust of spruce and beech, and also torrefied sawdust with different degrees of torrefaction. Dried sawdust was put in 10 clean and calibrated crucibles for each type of sawdust (specie and degree of torrefaction). These crucibles with sawdust were weighted before testing [27] and note this value as initial mass of sample. In order to protect the calciner oven, each sample with sawdust was burn over a gas flame up to no smoke was visible. Then, the crucibles were introduced inside of calciner at 650 °C and kept inside at least 2 hours. In the last hour from 10 in 10 minutes of calcination, the furnace door was opened to observe the calcination status. When the sparkling on the crucible is no longer visible and the ash has a grayish color it is considered that the calcination process is over. Then the crucibles are removed from the oven, cool in the desiccators and weigh the electronic balance with an accuracy of 0.001 g. This value represents the final mass of the ash crucible. With the mass values obtained during the test, the ash content (Ac) was calculated using the following calculation formula:

$$Ac = \frac{m_i - m_f}{m_i - m_c} \cdot 100\ [\%] \quad (4)$$

Where: m_i is initial mass of sawdust with crucible, in g; mf-final mass of sawdust with crucible, in g; m_c-mass of crucible, in g.

The obtained results were statistically processed, using the upper and lower limit values, the arithmetic mean, as well as the average square deviation, all of these parameters being obtained under the conditions that the probability of acceptance of the results exceeds 95%. All results were validated with other statistical methods.

3. RESULTS & DISCUSSION

3.1. Pellet Density

Mass losses during the torrefaction process have led to a decrease in the density of the pellets obtained from this type of sawdust. For example, the density of the beech pellets dropped from 0.851 g cm^{-3} for non-torrefied pellets to 0.641 g cm^{-3} for the 210/3 regime of torrefaction (decrease of 24.6%), and the density of the spruce pellets dropped from 0.883 g cm^{-3} for non-torrefied pellets to 0.622 g cm^{-3} for the 210/3 regime of torrefaction (29.5% decrease). Density of currently wooden pellets from the market [11] had a higher density of 1.1 g cm^{-3} because these pellets are made on the industrial installations, more strength than that are used in laboratories. The decrease was differentiated on the intervals of the thermal treatment regime, as seen in Fig 3, as follows:

-for beech pellets, from non-torrefied pellets to 170/3 torrefaction regime the pellet density decreased by 16.4%, further to 190/3 thermal regime it decreased by 4.9%, and up to 210/3 thermal regime it decreased by 4.5%;

-for spruce pellets, from non-torrefied pellets to 170/3 torrefaction regime the pellet density decreased by 17.1%, further down to 190/3 thermal regime it decreased by 9.8%, and up to 210/3 thermal regime it decreased by 6.1%.

According to expectations, the density of the pellets dropped significantly but with insignificant values from one species to another and almost imperceptible differences within each torrefaction regimes. The maximum decrease percent of pellet density was obtained on torrefaction of 170 °C, followed by 190 °C (Fig 4), the same influence being for beech and spruce pellets.

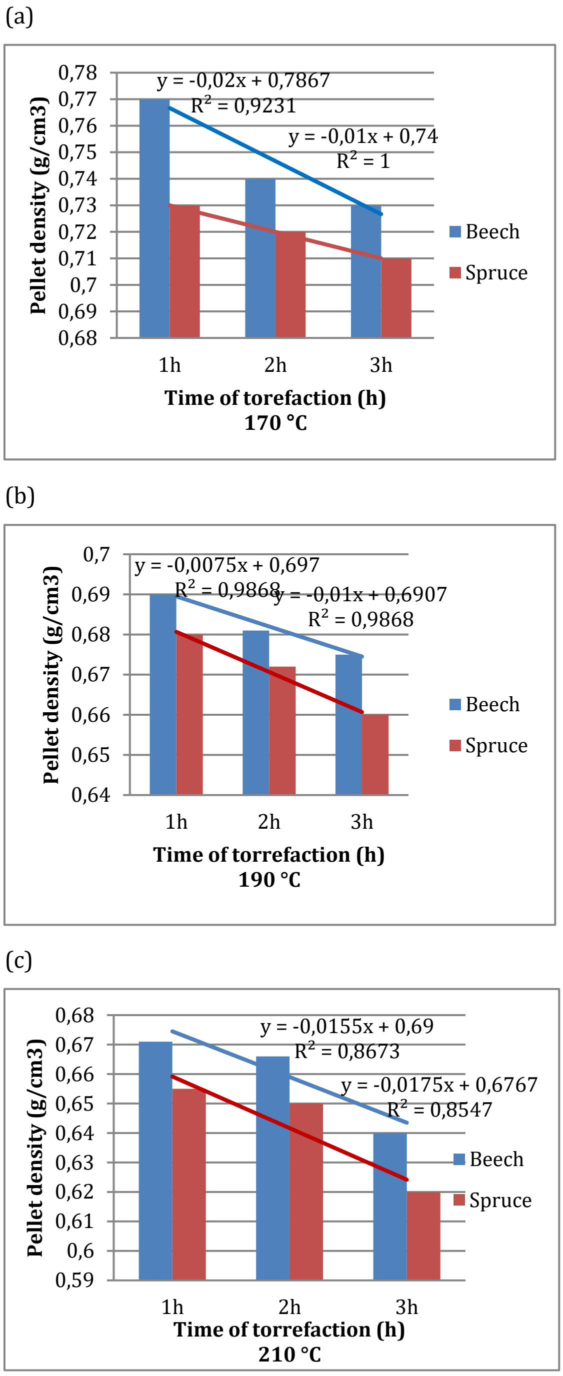


Fig 3. Density of torrefied pellets

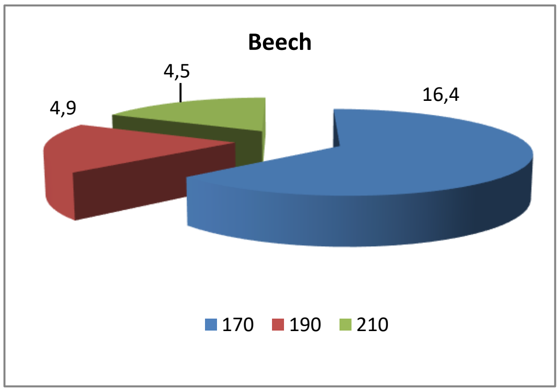


Fig 4. Decreasing in density related to torrefaction temperature for beech pellets

Another conclusion related to pellet density is that the density of beech pellets was higher than of spruce, because the density of beech specie was superior to that of spruce [11]. Because beech specie is a hard one the torrefaction process had a lower influence.

3.2. Calorific Value

There were obtained results for High Calorific Value (HCV) and Low Calorific Value (LCV) [28, 29]. As expected, the calorific power increased, due to carbonization of sawdust during torrefaction treatment. The maximum values of calorific value were determinate as 18976 kJ kg^{-1} for spruce and 19190 kJ kg^{-1} for beech pellets. Beyond these values, there were found the value of growth, differentiated by each regime of thermal treatment.

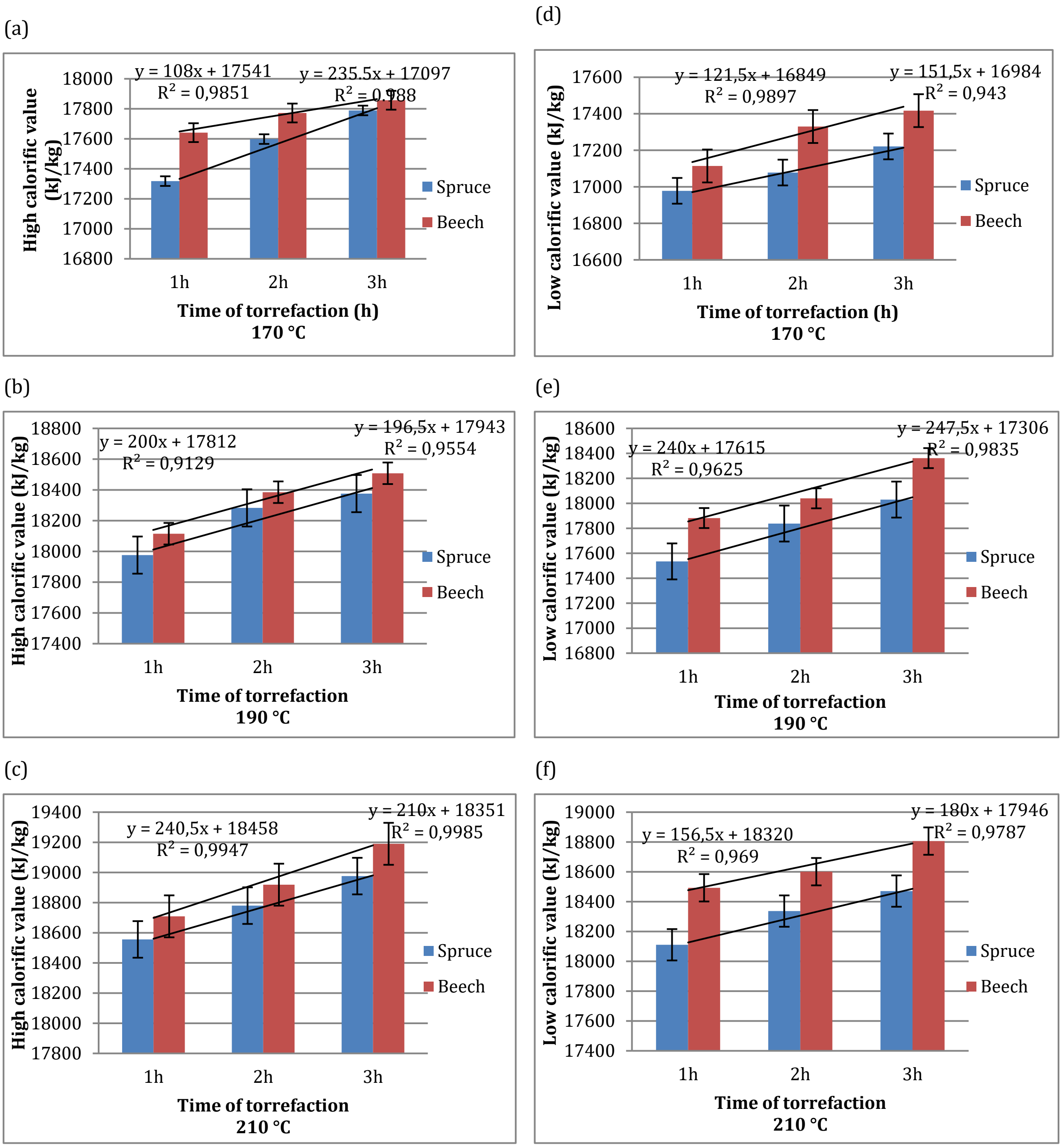


Fig 4. Calorific value of torrefied pellets

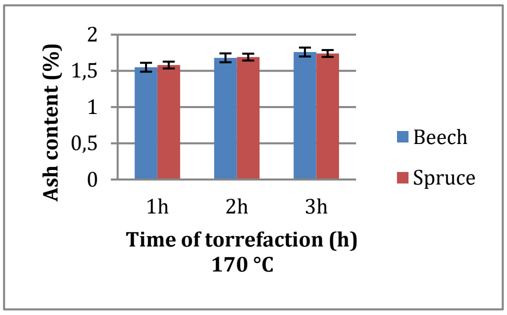
Total increase of calorific value was obtained for beech of 10.1% and 7.9% for spruce, to 95% probability of value accepting. This increase in calorific power is differentiated for thermal temperature as follows: for 170 °C the increase was of 3.7% for beech and 4.6% for spruce, for the temperature of 190 °C the increase was 4.5% for beech and 1.8% for spruce, and for the temperature of 210 °C the growth was of 2.6% for beech and 1.5% for spruce. It is clear that the temperature of 190 °C brought the highest increases in calorific value and the temperature of 210 °C brought the lowest increases, which means stopping the torrefaction treatment at 190 °C from the point of view of calorific value.

Taking charcoal as a comparison element with a specific calorific value of about 29300 kJ kg^{-1}, a high torrefaction reserve can be determined as 35.8%.

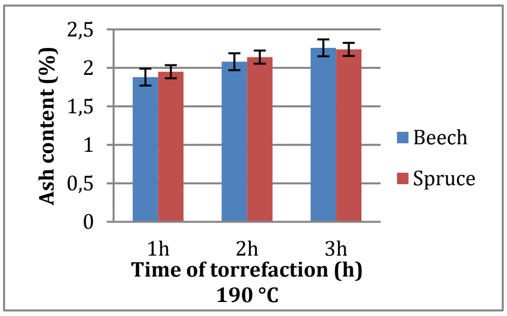
3.3. Ash Content

Minimal values of ash content were found for non-torefied sawdust, namely 1.48% for beech and 1.53% for spruce sawdust. Generally, the increase in the degree torrefaction of sawdust will increase proportionally with its ash content. This increase was 69.5% for beech sawdust and 65.3% for spruce. In regards with the ash contents increase in time of torrefaction process, when the beech pellets are taken into consideration, the maximum value is registered for the regime of 210/3 (2.51%), and the minimum value for the regime of 170/1 (1.55%). In case of the spruce pellets, the maximum value of the ash contents is registered for the regime of 210/3 hours (2.53%), and the minimum value for the regime of 170/1 hour (1.58%) (Fig 5).

(a)



(b)



(c)

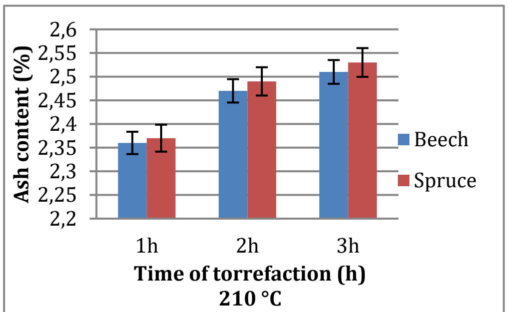
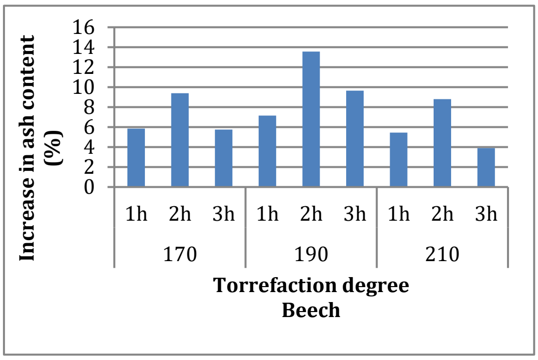


Fig 5. Variation of the ash contents for the two types of pellets, beech and spruce

Referring to the stages of beech sawdust torrefaction, if the whole interval of torrefied ash content is considered as unit (69.5%), this can be divided in three parts: part I, from control to 170 °C with 20.99%, part II, from 170 to 190 0C with 30.36%, and part III from 190 to 210 °C with 18.15%.

(a)



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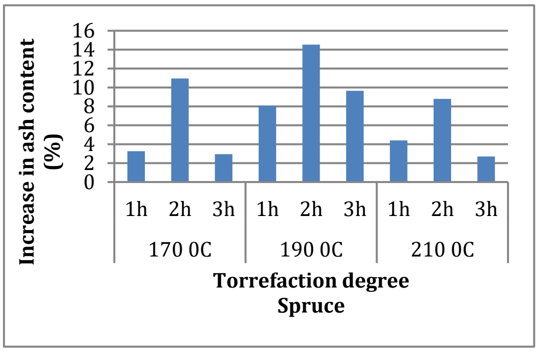

Fig 5. Increased percent of ash content related to torrefaction degree

Similarly, in the case of spruce sawdust the ash content growth range (65.3%) is divided into three parts: part I with 17.16%, part II with 32.24% and part III with 15.9%. Even if the values are little different from one species to another, the conclusions are clear: the temperature of 190 °C had the most influence of the ash content increase, and inside of the same temperature the strongest influence was the second hour. Taking into account that the term of comparison in this case is charcoal with an ash content of about 34% [30, 31], it is observed that there was a huge torrefaction reserve of about 2360%.

4. CONCLUSIONS

Beech and spruce sawdust were chosen for this research because these species are representative for hard and soft species. Sawdust is a kind of biomass as one of the oldest fuel materials, this way being fulfilled the protection of the environment. The torrefaction process in the range of 170-210 °C temperature, for 1, 2, and 3 hours has brought benefits particularly in terms of calorific value with a total increase of 10.1% for beech and 7.9% for spruce. Correlated with the decrease of pellet densities (with 24.6% for beech and 29.5% for spruce) the benefits are amplified and 1 bag of 10 kg will have more and better material. The temperature of 190 °C was the most one when the calorific value and ash content is taken into consideration. The maximum value of the superior calorific value of pellets were registered for the 210/3 regime with a value of 19 190 kJ kg^{-1} for beech and 18976 kJ kg^{-1} for spruce. Ash content of torrefied sawdust increased in time of thermal treatment with 69.5% for beech sawdust and 65.3% for spruce, with a large reserve vs. charcoal.

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